Reducing decoherence in an atomic-ion based quantum information processor

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Quantum Bits (qubits)

States and superposition

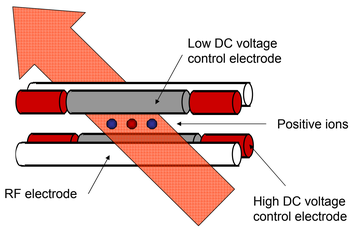
$|0\rangle$ $[\,|0\rangle + |1\rangle\,]/\sqrt{2}$

$|1\rangle$ $\alpha|0\rangle + \beta|1\rangle$

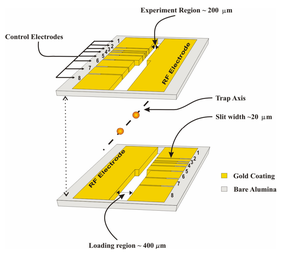
Entanglement $[\,|01\rangle + |10\rangle\,]/\sqrt{2}$

Quantum Information Processing with Trapped Ions

- Ions as qubits
- Quadrupole trap
- Manipulated with laser beams
- Ions can be entangled through vibrational modes



Six Zone Gold on Alumina Wafer Trap

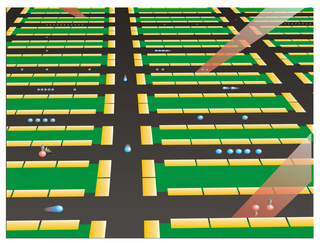


- Capable of handling several ions
- Ions be can separated and moved around in the trap
- A potentially scalable technology

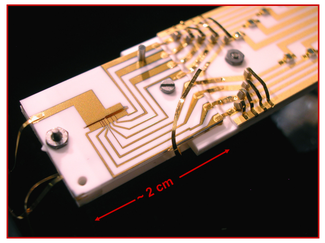
Murray Barret and John Jost, et al

Multiplexed Architecture

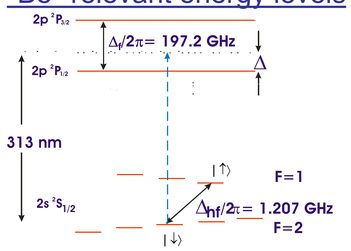
- Goal: to have only a small number of ions together at one time.
- Separate processing and memory regions



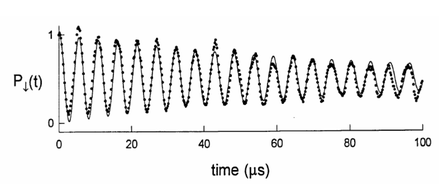
Experiments with Atomic Hyperfine Qubits



$^9Be^+$ relevant energy levels



Stimulated Raman Rabi flopping

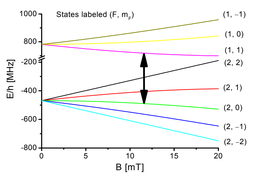


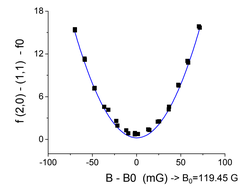
- The long life time of hyperfine ground states makes them a good choice for a qubit.
- Can discriminate between the qubit states with ~ 99% accuracy.
- These qubits are subject to many forms of decoherence: magnetic field noise, spontaneous emission, laser intensity fluctuations,….

B-field Insensitive Qubits:

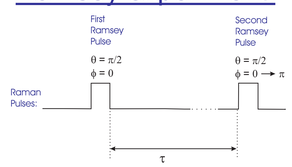
At certain B-fields the transition frequency between some hyperfine levels has zero first order differential Zeeman shift. Qubits based on these transitions have long coherence times and are a demonstrable robust quantum memory.

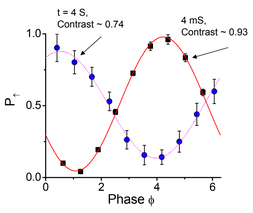
Breit-Rabi Solution

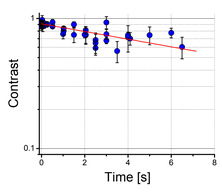




Ramsey experiment:







- An exponential fit to the contrast gives a coherence time of t = 14.76 +/- 1.6 S. Five orders of magnitude larger than our field dependent qubit coherence time.
- The coherence time is significantly longer than the gate time (~10 μS)

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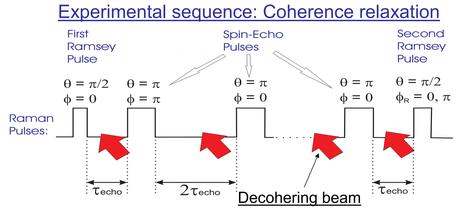
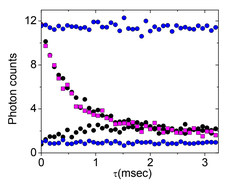
Experimental sequence: Coherence relaxation



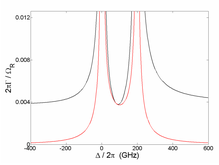
- Ramsey experiment.
- Echo sequence between Ramsey pulses.
- Population of $|\uparrow\rangle$ state measured vs. decohering beam duration, using state selective resonant fluorescence.

Decoherence, Optical Pumping, and Spontaneous Emission vs. Detuning



- Ramsey signal, upper, $\phi_R = 0$, lower $\phi_R = \pi$.
- Ramsey signal, in the absence of light.
- Population of $|\uparrow\rangle$ state.

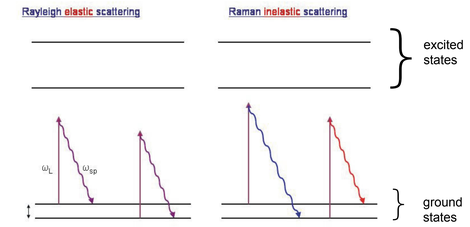
Number of photons scattered during a 2π pulse



- Total number of photons.
- Number of Raman photons.

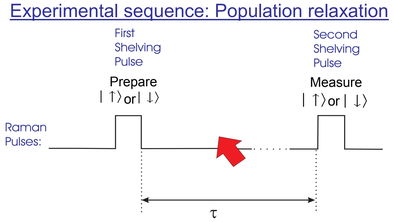
Coherence in the Presence of Spontaneous Scattering

Off resonance spontaneous photon scattering



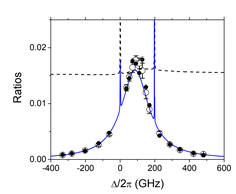
- NO information about the internal state of the atom is carried by the scattered photon.
- Scattered photon frequency and polarization are entangled with the atom's internal state.

Experimental sequence: Population relaxation



- Ion prepared in the $|\uparrow\rangle$ or the $|\downarrow\rangle$ states.
- Population of relevant state measured vs. decohering beam duration, using state selective resonant fluorescence.

Decoherence, Optical Pumping, and Spontaneous Emission vs. Detuning



- Calculated $\Gamma_{total}/\Delta_{St}$
- Calculated $\Gamma_{Raman}/\Delta_{St}$
- Measured $\Gamma_{Raman}/\Delta_{St}$
- Measured $1/(\tau_{dec}\Delta_{St})$

- The coherence of a superposition has been maintained even after undergoing 19 calculated Rayleigh elastic scattering events.
- The decoherence induced by spontaneous Raman scattering can be minimized by going to larger detunings.

R. Ozeri *et. al.* Phys. Rev. Lett. **95,** 030403 (2005)

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